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CHAPTER II

TRANSMITTAL LETTER
TO THE UNITED STATES ELECTED OFFICE (EO/US)

(ENTRY INTO U.S. NATIONAL PHASE UNDER CHAPTER II)

PCT/RU99/000272	04/August/1999	3/September/1998
INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED

IMAGE PROCESSING METHOD
TITLE OF INVENTION

Semenchenko, Mikhail Grigorievich
APPLICANT(S)

Box PCT
Assistant Commissioner for Patents
Washington D.C. 20231
ATTENTION: EO/US

NOTE: *To avoid abandonment of the application, the applicant shall furnish to the USPTO, not later than 20 months from the priority date: (1) a copy of the international application, unless it has been previously communicated by the International Bureau or unless it was originally filed in the USPTO; and (2) the basic national fee (see 37 C.F.R. § 1.492(a)). The 30-month time limit may not be extended. 37 C.F.R. § 1.495.*

WARNING: *Where the items are those which can be submitted to complete the entry of the international application into the*

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national phase are subsequent to 30 months from the priority date the application is still considered to be in the international state and if mailing procedures are utilized to obtain a date the express mail procedure of 37 C.F.R. §1.10 <u>must</u> be used (since international application papers are not covered by an ordinary certificate of mailing - See 37 C.F.R. §1.8.

NOTE: Documents and fees must be clearly identified as a submission to enter the national state under 35 USC 371 otherwise the submission will be considered as being made under 35 USC 111. 37 C.F.R. § 1.494(f).

1. Applicant herewith submits to the United States Elected Office (EO/US) the following items under 35 U.S.C. 371:

    a. [X] This express request to immediately begin national examination procedures (35 U.S.C. 371(f)).

    b. [X] The U.S. National Fee (35 U.S.C. 371(c)(1)) and other fees (37 C.F.R. § 1.492) as indicated below:

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2.Fees

CLAIMS FEE	(1) FOR	(2) NUMBER FILED	(3) NUMBER EXTRA	(4) RATE	(5) CALCULA-TIONS
[ ]*	TOTAL CLAIMS	26 - 20 =	6	x $ 18.00 =	$108.00
	INDEPENDENT CLAIMS	1 - 3 =	0	x $ 78.00 =	
	MULTIPLE DEPENDENT CLAIM(S) (if applicable) + $260.00				
BASIC FEE**	[ ] U.S. PTO WAS INTERNATIONAL PRELIMINARY EXAMINATION AUTHORITY Where an International preliminary examination fee as set forth in § 1.482 has been paid on the international application to the U.S. PTO: [ ] and the international preliminary examination report states that the criteria of novelty, inventive step (non-obviousness) and industrial activity, as defined in PCT Article 33(2) to (4) have been satisfied for all the claims presented in the application entering the national stage (37 CFR 1.492(a)(4)) .... $96.00 [ ] and the above requirements are not met (37 CFR 1.492(a)(1)) .... $670.00 [X] U.S. PTO WAS NOT INTERNATIONAL PRELIMINARY EXAMINATION AUTHORITY Where no international preliminary examination fee as set forth in § 1.482 has been paid to the U.S. PTO, and payment of an international search fee as set forth in § 1.445(a)(2) to the U.S. PTO: [ ] has been paid (37 CFR 1.492(a)(2)) .... $760.00 [ ] has not been paid (37 CFR 1.492(a)(3)) .... $970.00 [X] where a search report on the international application has been prepared by the European Patent Office or the Japanese Patent Office (37 CFR 1.492(a)(5)) $860.00					$860.00
	Total of above Calculations				= $968.00
SMALL ENTITY	Reduction by ½ for filing by small entity, if applicable. Affidavit must be filed. (note 37 CFR 1.9, 1.27, 1.28)				- $484.00
	Subtotal				$484.00
	Total National Fee				$ 484.00
	Fee for recording the enclosed assignment document $40.00 (37 CFR 1.21(h)). (See Item 13 below). See attached "ASSIGNMENT COVER SHEET".				
TOTAL	Total Fees enclosed				$ 484.00

*See attached Preliminary Amendment Reducing the Number of Claims.

i. [ ] A check in the amount of ___________ to cover the above fees is enclosed.

ii. [X] Please charge Account No. 18-0013 in the amount of $ 484.00 . A duplicate copy of this sheet is enclosed.

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WARNING: *If the translation of the international application and/or the oath or declaration have not been submitted by the applicant within thirty (30) months from the priority date, such requirements may be met within a time period set by the Office. 37 C.F.R. § 1.495(b)(2). The payment of the surcharge set forth in § 1.492(e) is required as a condition for accepting the oath or declaration later than thirty (30) months after the priority date. The payment of the processing fee set forth in § 1.492(f) is required for acceptance of an English translation later than thirty (30) months after the priority date. Failure to comply with these requirements will result in abandonment of the application. The provisions of § 1.136 apply to the period which is set. Notice of Jan. 3, 1993, 1147 O.G. 29 to 40.*

3. [X] A copy of the International application as filed (35 U.S.C. 371(c)(2)):

NOTE: *Section 1.495 (b) was amended to require that the basic national fee and a copy of the international application must be filed with the Office by 30 months from the priority date to avoid abandonment "The International Bureau normally provides the copy of the international application to the Office in accordance with PCT Article 20. At the same time, the International Bureau notifies applicant of the communication to the Office. In accordance with PCT Rule 47.1, that notice shall be accepted by all designated offices as conclusive evidence that the communication has duly taken place. Thus, if the applicant desires to enter the national stage, the applicant normally need only check to be sure the notice from the International Bureau has been received and then pay the basic national fee by 30 months from the priority date." Notice of Jan. 7, 1993, 1147 O.G. 29 to 40, at 35-36. See item 14c below.*

a. [X] is transmitted herewith.

b. [ ] is not required, as the application was filed with the United States Receiving Office.

c. [ ] has been transmitted

i. [ ] by the International Bureau.
Date of mailing of the application (from form PCT/IB/308): __________.

ii. [ ] by applicant on ______.
Date

4. [X] A translation of the International application into the English language (35 U.S.C. 371(c)(2)):

a. [ ] is transmitted herewith.

b. [X] is not required as the application was filed in English.

c. [ ] was previously transmitted by applicant on ________________.
Date

d. [ ] will follow.

5. [X] Amendments to the claims of the International application under PCT Article 19 (35 U.S.C. 371(c)(3)):

NOTE: The Notice of January 7, 1993 points out that 37 C.F.R. § 1.495(a) was amended to clarify the existing and continuing practice that PCT Article 19 amendments must be submitted by 30 months from the priority date and this deadline may not be extended. The Notice further advises that: "The failure to do so will not result in loss of the subject matter of the PCT Article 19 amendments. Applicant may submit that subject matter in a preliminary amendment filed under section 1.121. In many cases, filing an amendment under section 1.121 is preferable since grammatical or idiomatic errors may be corrected." 1147 O.G. 29-40, at 36.

a. [ ] are transmitted herewith.
b. [ ] have been transmitted
 i. [ ] by the International Bureau.
 Date of mailing of the amendment (from form PCT/IB/308): __________.
 ii. [ ] by applicant on _______.
 Date
c. [X] have not been transmitted as
 i. [X] applicant chose not to make amendments under PCT Article 19.
 Date of mailing of Search Report (from form PCT/ISA/210): __________.
 ii. [ ] the time limit for the submission of amendments has not yet expired. The amendments or a statement that amendments have not been made will be transmitted before the expiration of the time limit under PCT Rule 46.1.

6. [ ] A translation of the amendments to the claims under PCT Article 19 (38 U.S.C. 371(c)(3)):
 a. [ ] is transmitted herewith.
 b. [ ] is not required as the amendments were made in the English language.
 c. [ ] has not been transmitted for reasons indicated at point 5(c) above.

7. [ ] A copy of the international examination report (PCT/IPEA/409)
 [ ] is transmitted herewith.
 [ ] is not required as the application was filed with the United States Receiving Office.

8. [ ] Annex(es) to the international preliminary examination report
 a. [ ] is/are transmitted herewith.
 b. [ ] is/are not required as the application was filed with the United States Receiving Office.

9. [ ] A translation of the annexes to the international preliminary examination report
 a. [ ] is transmitted herewith.
 b. [ ] is not required as the annexes are in the English language.

10. [X] An oath or declaration of the inventor (35 U.S.C. 371(c)(4)) complying with 35 U.S.C. 115
 a. [ ] was previously submitted by applicant on ____________.
 Date
 b. [X] is submitted herewith, and such oath or declaration
 i. [X] is attached to the application.
 ii. [ ] identifies the application and any amendments under PCT Article 19 that were transmitted as stated in points 3(b) or 3(c) and 5(b); and states that they were reviewed by the inventor as required by 37 C.F.R. 1.70.

iii. [ ] will follow.

Other document(s) or information included:

11. [X] An International Search Report (PCT/ISA/210) or Declaration under PCT Article 17(2)(a):
  - a. [X] is transmitted herewith.
  - b. [ ] has been transmitted by the International Bureau.
    Date of mailing (from form PCT/IB/308): ________________.
  - c. [ ] is not required, as the application was searched by the United States International Searching Authority.
  - d. [ ] will be transmitted promptly upon request.
  - e. [ ] has been submitted by applicant on ________________.
    Date

12. [X] An Information Disclosure Statement under 37 C.F.R. 1.97 and 1.98:
  - a. [ ] is transmitted herewith.
    Also transmitted herewith is/are:
    [ ] Form PTO-1449 (PTO/SB/08A and 08B).
    [ ] Copies of citations listed.
  - b. [X] will be transmitted within THREE MONTHS of the date of submission of requirements under 35 U.S.C. 371(c).
  - c. [ ] was previously submitted by applicant on ________________.
    Date

13. [ ] An assignment document is transmitted herewith for recording.

A separate [ ] "COVER SHEET FOR ASSIGNMENT (DOCUMENT) ACCOMPANYING NEW PATENT APPLICATION" or[ ] FORM PTO 1595 is also attached.

____
____
____

14. [X] Additional documents:
  - a. [ ] Copy of request (PCT/RO/101)
  - b. [X] International Publication No. WO 00/14684
    - i. [ ] Specification, claims and drawing
    - ii. [X] Front page only
  - c. [ ] Preliminary amendment (37 C.F.R. § 1.121)
  - d. [ ] Other

____
____
____

15. [X] The above checked items are being transmitted

a. [X] before 30 months from any claimed priority date.
b. [ ] after 30 months.

16. [ ] Certain requirements under 35 U.S.C. 371 were previously submitted by the applicant on ______________, namely:

____
____
____

AUTHORIZATION TO CHARGE ADDITIONAL FEES

WARNING: *Accurately count claims, especially multiple dependent claims, to avoid unexpected high charges if extra claims are authorized.*

NOTE: *"A written request may be submitted in an application that is an authorization to treat any concurrent or future reply, requiring a petition for an extension of time under this paragraph for its timely submission, as incorporating a petition for extension of time for the appropriate length of time. An authorization to charge all required fees, fees under § 1.17, or all required extension of time fees will be treated as a constructive petition for an extension of time in any concurrent or future reply requiring a petition for an extension of time under this paragraph for its timely submission. Submission of the fee set forth in § 1.17(a) will also be treated as a constructive petition for an extension of time in any concurrent reply requiring a petition for an extension of time under this paragraph for its timely submission." 37 C.F.R. § 1.136(a)(3).*

NOTE: *"Amounts of twenty-five dollars or less will not be returned unless specifically requested within a reasonable time, nor will the payer be notified of such amounts; amounts over twenty-five dollars may be returned by check or, if requested, by credit to a deposit account." 37 C.F.R. § 1.26(a).*

[X] The Commissioner is hereby authorized to charge the following additional fees that may be required by this paper and during the entire pendency of this application to Account No. <u>18-0013</u>.

[X] 37 C.F.R. 1.492(a)(1), (2), (3), and (4) (filing fees)

WARNING: *Because failure to pay the national fee within 30 months without extension (37 C.F.R. § 1.495(b)(2)) results in abandonment of the application, it would be best to always check the above box.*

[X] 37 C.F.R. 1.492(b), (c) and (d) (presentation of extra claims)

NOTE: *Because additional fees for excess or multiple dependent claims not paid on filing or on later presentation must only be paid or these claims cancelled by amendment prior to the expiration of the time period set for response by the PTO in any notice of fee deficiency (37 C.F.R. § 1.492(d)), it might be best not to authorize the PTO to charge additional claim fees, except possible when dealing with amendments after final action.*

[X] 37 C.F.R. 1.17 (application processing fees)
[X] 37 C.F.R. 1.17(a)(1)-(5)(extension fees pursuant to § 1.136(a).
[ ] 37 C.F.R. 1.18 (issue fee at or before mailing of Notice of Allowance, pursuant to 37 C.F.R. 1.311(b))

NOTE: *Where an authorization to charge the issue fee to a deposit account has been filed before the mailing of a Notice of Allowance, the issue fee will be automatically charged to the deposit account at the time of mailing the notice of*

allowance. 37 C.F.R. § 1.311(b).

NOTE: 37 C.F.R. 1.28(b) requires "Notification of any change in loss of entitlement to small entity status must be filed in the application . . . prior to paying, or at the time of paying . . . issue fee." From the wording of 37 C.F.R. § 1.28(b): (a) notification of change of status must be made even if the fee is paid as "other than a small entity" and (b) no notification is required if the change is to another small entity.

[X] 37 C.F.R. § 1.492(e) and (f) (surcharge fees for filing the declaration and/or filing an English translation of an International Application later than 30 months after the priority date).

SIGNATURE OF PRACTITIONER

Reg. No.: 37,425

Alexander D. Rabinovich
(type or print name of practitioner)

Tel. No.: (248) 594-0622

RADER, FISHMAN & GRAUER PLLC
P.O. Address
39533 Woodward Ave., Suite 140
Bloomfield Hills, MI 48304

CUSTOMER NO.: 010291

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IMAGE PROCESSING METHOD

TECHNICAL FIELD

The present invention relates to the automatics and computation techniques and, more particularly, to methods of the preliminary image processing for sharpening and contrast enhancement.

BACKGROUND ART

One of the methods known in the prior art is described in the Russian Patent No.2015561, published on 16.04.91, Int. Class G06K 9/40. According to this invention, the image correction is made basing on the analysis of the original image at the processing pixel and the local average value over some neighborhood of this pixel.

The method of that patent smoothes the original image, thus producing the smoothed image containing the low frequency components presenting the image background. Then the smoothed image is subtracted from the original one producing the second image containing high frequency components without background, said second image is then emphasized and added to the smoothed image.

The disadvantage of this method is that it emphasizes not only the useful signal but also the noise containing in high frequency image components, thus degrading the quality of the enhanced image.

The method according to U.S. Patent No. 5,038,388, published on 06.08.91, Int. Class G06K 9/40 smoothes the original image and subtracts the smoothed image from the original one thus producing the second image containing the high frequency image components only. Said second image is then adaptively emphasized so that the scaling factor is then higher than larger is a difference between the processing pixels and its neighborhood. The output image is produced by adding the adaptively emphasized second image to the original image, thus sharpening the image without the noise amplification.

The solution described in this patent does not provide any noise suppression as this method can only emphasize the high frequency image components that may contain a noise.

Furthermore, the disadvantage of this method known in the art is that it fails to improve considerably the sharpness of weak edges as such enhancement requires to emphasize the high frequency image components in the regions where a difference between the processing pixel and its neighborhood is comparable to the noise level. Therefore the edge enhancement in such regions causes the noise emphasis.

According to the image processing method disclosed in U.S. Patent No. 5,381,490, published on 10.01.95, Int. Class G06K 9/40 the largest difference Δ

between the processing pixel and its nearest neighbors is calculated. Depending on the magnitude of this difference, one of the three processing modes is selected:

- the edge enhancement by means of emphasis of the high frequency image components if $\Delta > T_1$, here T_1 presents the first pre-defined threshold value;
- reproduction of the original image, if $T_2 < \Delta < T_1$, where T_2 stands for the second pre-defined threshold value.
- the image smoothing to suppress a noise, if $\Delta < T_2$.

The first disadvantage of this method is that it may emphasize the noise selectively if the difference Δ varies around any of the threshold values for some neighboring pixels thus transforming small differences between neighboring pixels into larger ones by involving different processing modes for these neighboring pixels.

Furthermore, this method fails to provide quality enhancement of images with different noise magnitudes without tuning as the threshold values T_1 and T_2 are not selected adaptively.

Another approach to the noise suppression in images is described in U.S. Patent 5,563,963, published on 08.10.96, Int. Class G06K 9/40. The method of this patent operates by selecting a plurality of groups of neighbors for each pixel of the original image, each group being a square containing N x N pixels, here N varies for example from 2 to 21. The processing pixel may be located at any position inside this square group of pixels. The least square best fit plane (the planar approximation) is used then to approximate pixel values in each of selected pixel groups and the new value for the processing pixel and the goodness of fit are computed basing on said approximation for each group.

The target pixel of an enhanced image is produced by the weighted summing of all the new pixel values, the weight of a group is then higher than higher is the goodness of fit for this group.

The disadvantage of this method is that it fails to enhance edges as this method provides the noise smoothing only. Furthermore, this method requires huge computation efforts to build least square approximations by hundreds of groups for each of hundreds of thousands of pixels.

A technique for making low contrast parts of a digital image more perceptible is disclosed in the European Patent EP 0 756 247 A1, published on 29.01.97, Int. Cl. G06T 5/20. This method decomposes the original image into plurality of images in such a way that these images belong to different isotropic frequency bands. Thereat the image presenting the low frequency components of the original image has lower resolution (smaller size) than the image presenting the high frequency components. The emphasis processing is carried out on these images. The degree of emphasis is selected to be lower for pixels having values larger than a predetermined threshold value than for pixels having small values. The output image is assembled from the processed images.

The disadvantage of this method is that it emphasizes noise as well as the useful signal. This method fails to provide the edge detection and enhancement as the isotropic frequency channels are used.

The method disclosed in U.S. Patent 5,739,922, published on 14.04.98, Int. Classes G06K 9/40, H04N 1/40 operates by splitting of the original color image into three isotropic frequency channels: the low frequency image components (LF), the medium frequency components (MF) and the high frequency

components (HF). The adaptive emphasis of the HF components and adaptive suppression of the MF components is then carried out, thereat the multipliers for HF and MF image components are then higher than higher is a correlation between at least two of three basic image colors. The enhanced image is obtained by summing LF image components with adaptively suppressed MF components and adaptively emphasized HF image components.

The image processing method and apparatus described in said patent may have the limited application as they are suitable for color images only as the correlation between color components is used for carrying out the image processing.

Furthermore, the noise suppression according to this invention is significantly limited, as the HF image components, that also contain a noise, may be emphasized only and the noise suppression in MF image components is limited because no directional splitting of the original image is used.

The edge detection and enhancement can not be obtained by this method as the isotropic frequency channels are used.

All these disadvantages degrade the quality of enhanced images.

The most relevant image processing method is described in U.S. Patent No. 5,351,305, published on 27.09.94, Int. Class G06K 9/40. According to this patent, a plurality of directionally filtered images is obtained from the original image by applying directional filters in the frequency domain. The enhanced image is then formed by selecting each target pixel either from the directionally filtered image, if the contrast edge is detected nearby the processing pixel or from the original image otherwise. Thereat the contrast edge is detected nearby the processing pixel

by generating the standard deviation image and by producing the eigenvector description of this image. The eigenvector length is compared to the pre-determined threshold value to detect an edge.

The target pixel is equal to the corresponding pixel of the original image, if the edge was not detected nearby. Otherwise, the target pixel is selected from an image filtered with the most nearly corresponding direction of filtering.

While detecting edges, the eigenvector length may vary around the threshold value for several adjacent pixels. Thereby the neighboring pixels of the enhanced image are selected from different images (the original image and directionally filtered image) thus causing the selective noise emphasis. This emphasis degrades the enhanced image quality.

Furthermore, original images may differ in their noise levels thus requiring different threshold values. This method does not include the adaptive selection of the threshold value and therefore may not provide high quality processing of images with different noise levels.

Provided that the edge is detected nearby, the selection of pixels of the enhanced image is made from one of plurality of directionally filtered images thus causing the complete suppression of all image structures that differ by their direction from the detected edge, notwithstanding that those structures can be clearly seen in the original image.

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DISCLOSURE OF INVENTION

The object of the claimed invention is to provide a method for enhancing the image sharpness and contrast combined with simultaneous noise suppression.

The said objective is achieved in the image processing method, comprising the presentation of the original image as a matrix of the discreet picture elements (pixels), splitting of the original image into n frequency channels, each channel presented by an image matrix of the same size as the original image, the edge detection and assembling of the output image from said n frequency channels taking the detected edges into account, by splitting of the original image into the low frequency channel and n-1 high frequency channels and edge detection by computation in each of n-1 selected high frequency channels of the correlation between processing pixel and its neighboring pixels, followed by the comparison of said correlation value with that for the corresponding pixels in other high frequency channels and with the threshold value for this channel. Basing on the results of comparison, the weighting coefficients are formed for each pixel of each of n-1 high frequency channels, and the assembly of the output image is made by summing each pixel from the low frequency channel with all products of the corresponding (by their location in the image) pixels of n-1 high frequency channels by their weighting coefficients.

The said objective is also achieved by selection of m of n-1 high frequency channels (2<m<=n-1) in such a way that they differ one from another in the direction of principal passing only. Therewithal, the weighting coefficients for any of pixels of any of m high frequency channels is defined basing on the comparison

of its correlation value to the threshold value and to the correlation values of the corresponding (by their location in the image) pixels of other m-1 high frequency channels.

The said objective is also achieved by computation of said correlation as a product of the processing pixel value and the weighted sum of its neighbors, said weights being anisotropic thereat the direction of this anisotropy corresponds to the direction of principal passing of the processing channel.

Furthermore, the threshold value for any of n-1 high frequency channels is determined by analysis of distribution of values, or absolute values, of pixels in this channel. The threshold value may be also determined by analysis of distribution of values, or absolute values, of pixels of the original image.

The claimed as the invention image processing method is characterized by the following features that distinguish it from the most relevant method known in the prior art:

1. while splitting the original image into frequency channels, the low frequency channel and n-1 high frequency channels are selected;
2. the value of correlation between the processing pixel and its neighboring pixels is used to detect edges in the image. More specifically, the value of said correlation is compared to the correlation values for the corresponding (by their location in the image) pixels in other n-1 high frequency channels and to the threshold value for this channel. The weighting coefficients for all pixels of n-1 high frequency channels are generated as a result of this comparison.

3. the output image is assembled by means of summing of each pixel from the low frequency channel and all the corresponding (by their location) pixels from n-1 high frequency channels multiplied by their weighting coefficients.

Concerning the first feature it should be noted that the extraction of the low frequency channel that is not a subject of any processing provides the distortion free reproduction of large-scale objects of the original image in the enhanced image, as these objects are passed through the low frequency channel without any processing. Therewithal the energy of noise passing through the low frequency channel without suppression is low as most of the noise energy is concentrated at high frequencies.

Furthermore, the extraction of the low frequency channel helps reduce the computation efforts needed to find correlation values for n-1 high frequency channels, as the subtraction of the local average value is required to compute correlation. This subtraction is made while extracting (subtracting from the original image) the low frequency channel.

The splitting of the original image into several high frequency channels helps improve, compared to selection of one or two channels, the noise suppression, as a noise associated with pixels of those frequency channels where edges were not found nearby, is prevented from contributing to the enhanced image.

Concerning the second feature it should be noted that edge detection by means of the correlation value between the processing pixel and its neighbors allows to find weak edges on a noisy background as the correlation value is close to zero for the typical noise, thereat the correlation values for adjacent pixels forming the edge are positive and of similar magnitude. This difference in correlation behavior

helps achieve the high noise suppression combined with edge emphasis thus increasing the image sharpness and contrast.

The edge detection basing on the correlation between a processing pixel and its neighbors provides a quantitative measure of the edge intensity for each image pixel. This allows performing the selective emphasis of edges having certain intensity, for example, the weak edges. Furthermore, use of the correlation between the pixel and its neighbors makes the method of the present invention applicable to various types of images, including, for example, color and gray scale images, as well as three-dimensional images.

The third specific feature, namely assembling of the enhanced image by weighted summing of images from all frequency channels, helps to remove completely the effect of the selective noise emphasis. This effect is caused by selection of neighboring pixels from different frequency channels.

Furthermore, the determination of the threshold value by means of analysis of statistical distribution of pixels provides a high quality processing of images with materially different noise magnitudes without changing of parameters.

Furthermore, use of anisotropic frequency channels and anisotropic weights makes the image processing method highly sensitive to weak edges.

BRIEF DESCRIPTION OF DRAWINGS

The claimed invention is illustrated by the drawings of the apparatus that implements the claimed method.

Fig.1 is a block diagram of the apparatus.

The preferred embodiment of the sub-units of said apparatus are shown in more details at Fig. 2 - 5:

Fig.2 is a block diagram of the frequency channel splitting unit (splitting unit).

Fig.3 is a block diagram of the unit for computation of correlations (correlation unit).

Fig.4 is a block diagram of the unit for forming of the weighting coefficients (weighting unit).

Fig.5 is a block diagram of the unit to assemble the output image (assembling unit).

Fig.6 shows an example of the pre-defined channel selection matrixes.

Fig.7 illustrates the operation of the frequency channel splitting unit.

Fig.8 is a graph showing an example of the dependence of the weighting coefficient on the correlation value.

Referring to Fig.1, the apparatus contains the image source 1, the output of said image source connected to the input of the splitting unit 2. The low frequency output 7 of said unit 2 is connected to the input 9 of the assembling unit 5, all other outputs of said splitting unit are connected to the corresponding inputs of the correlation unit 3, said other outputs are also connected to the inputs 10_1 - 10_4 of the assembling unit 5. The outputs of said correlation unit 3 are connected to the corresponding inputs of the weighting unit 4, the outputs of said weighting unit are the inputs 8_1 - 8_4 of the assembling unit 5. Thereat the output of said assembling

unit 5 is connected to the input of the memory unit 6, the output of said memory unit is an output of the apparatus.

Fig.2 shows more in details the preferred embodiment of the splitting unit 2. It includes the direct Fourier processor 11, the input of said processor is connected to the output of image source 1, the output of said direct Fourier processor 11 is connected to the first inputs of matrix multiplicators 12_0 - 12_4 The second inputs of said multiplicators are connected to the corresponding memory units, said memory units hold the pre-defined channel selection matrixes illustrated at Fig.6. Any of the matrix multiplicators 12_0 - 12_4 performs the element-by-element multiplication of matrixes supplied to its two inputs. The outputs of said matrix multiplicators 12_0 - 12_4 are connected to the inputs of the inverse Fourier processors 14_0 - 14_4. The output of the inverse Fourier processor 14_0 is connected to the input 9 of the assembling unit 5, and outputs of the inverse Fourier processors 14_1 - 14_4 are connected to the inputs 10_1 - 10_4 of the assembling unit as well as to the corresponding inputs of the correlation unit 3.

Fig.3 shows more in details the correlation unit 3. The memory unit 15 holds the image of the processing frequency channel. The input of said memory unit is the input of the correlation unit. It is connected also to the input of the noise level measuring unit 20, the output of said unit is connected to the first input of divider 19. The second input of said divider is connected to the output of multiplicator 18. The first input of said multiplicator is connected to the first output of the memory unit 15. Other outputs of said memory unit are connected to the weighting summator 17, the output of said weighting summator is the second input of multiplicator 18. The address input of the memory unit 15 is connected to

the address generator 16. The output of divider 19 is the output of the correlation unit.

The noise level measuring unit 20 may be implemented according to the U.S. Patent No. 5,657,401, published on 12.08.97, Int. Class G06K 9/40.

All the memory units are of the random access memory type and they are well known in the art.

The weighting summator 17 may be implemented as eight scalar multiplicators (the number of said multiplicators is equal to the number of adjacent pixels). Any of said scalar multiplicators has two equal inputs and one output. The outputs of all said multiplicators are connected to the inputs of summator, the output of said summator is the output of unit 17. The first inputs of said multiplicators are the inputs of the unit 17 and the pre-defined weighting coefficients are supplied to the second inputs of said multiplicators.

Fig.4 shows the weighting unit 4. The four inputs of the weighting unit 4 are the inputs of four rounding units 23_1 - 23_4, the outputs of said rounding units are connected to the inputs of the address assembling unit 24. The output of said unit 24 is connected to inputs of four look-up tables 25_1 - 25_4. The look-up table is a memory unit that stores the values of the weighting coefficient for any set of the four input correlation values. The outputs of the look-up tables 25_1 - 25_4 are connected to the inputs of the memory units 26_1 - 26_4, said memory units accumulate values of weighting coefficients. The address inputs of the memory units 26_1 - 26_4 are connected to the address generator 27 and the outputs of said memory units are connected to the inputs of summators 28_1 - 28_4 for averaging of

weighting coefficients. The outputs of said summators are the outputs of the weighting unit 4.

Fig.5 shows the assembling unit 5. It consists of four multiplicators 29_1 - 29_4 and summator 30. The first inputs $8_1 - 8_4$ of said multiplicators are connected to the outputs of the weighting unit 4 and the second inputs $10_1 - 10_4$ of said multiplicators are connected to the outputs of the splitting unit 2. The outputs of multiplicators $29_1 - 29_4$ are connected to the corresponding inputs of the summator 30 and the input 9 of said summator is connected to the output 7 of the splitting unit 2. The output of summator 30 is connected to the input of the memory unit 6 that accumulates an enhanced image.

BEST MODE FOR CARRYING OUT THE INVENTION

The apparatus implements the claimed method as it is described hereinafter. Referring to Fig.1, the input image is generated by the image source 1. The MRI unit may be used, for example, as an image source 1. Said MRI unit produces the image of the cross-section of an object, this image being a matrix containing discreet picture elements (pixels). Said image is carried to the input of the splitting unit 2. The operation of the splitting unit 2 is described with a reference to Fig.2 and Fig.7. The input image is transformed to the frequency presentation by the direct Fourier processor 11. Said frequency presentation contains the complete

information about the original image and is represented by the matrix of the same size as an input image. This matrix is passed to identical matrix multiplicators

12_0 - 12_4, these matrix multiplicators perform the element-by-element multiplication of the frequency presentation of the original image by pre-defined channel selection matrixes. Said channel selection matrixes are stored in memory units 13_0 - 13_4. Each channel selection matrix contains the multipliers for all spatial frequencies of the frequency image presentation. Fig.6 shows the examples of the channel selection matrixes.

More specifically, as an image is presented by a 2D matrix, its frequency presentation is also a 2D matrix. Fig.6a shows schematically a frequency presentation matrix. The horizontal and vertical spatial frequencies vary along axes k_x and k_y, respectively.

The zero spatial frequency corresponds to the constant image density. It is located at the crossing point (31) of axes k_x and k_y.

Points 32 and 33 represent the largest spatial frequency in horizontal direction. The examples of images contributing to these points are shown in drawings 34 and 35.

Similarly, the maximal spatial frequency in the vertical direction is located at points 36 and 37; the example of image contributing to these points is illustrated by drawing 38.

The maximal spatial frequencies are located at points 39 - 42. The example of an image contributing to these maximal spatial frequencies is shown in drawing 43.

Medium spatial frequency in horizontal direction is located at point 45. The example of image contributing to this point is shown in drawing 44.

The location of the spatial frequencies in drawings Fig.6(b-f) corresponds to the scheme depicted in Fig.6a.

Fig.6b shows schematically the pre-defined selection matrix for the low frequency channel, said matrix being stored in the memory unit 13_0.

The dark area 46 is filled by the unit values of the matrix elements. This area corresponds to spatial frequencies that pass through the low frequency channel. The white region is filled by the zero values of the matrix elements, therefore the frequencies of the white region do not pass through the low frequency channel.

Fig.6(c-f) show schematically the selection matrixes for four high frequency channels, thereat the same notations as in Fig.6b are used.

It should be noted that the sum of all channel selection matrixes Fig.6(b-f) is the matrix with all elements equal to 1. Therefore all the information from the original image passes through at least one channel.

Referring to Fig.2, each of the matrix multiplicators 12_0 - 12_4 forms on its output the matrix of the corresponding frequency channel in the frequency presentation. The inverse Fourier processors 14_0 - 14_4 transform said matrixes to the coordinate presentation.

The direct Fourier processor 11 and inverse Fourier processors 14_0 - 14_4 may be implemented basing on the Fast Fourier Transform algorithm as described,

for example, in: Cooley, J.M., Lewis, P.A.W. and Welch, P.D. (1969) The finite Fourier transform. I.E.E.E. Trans. Audio Electroacoustics AU-17, 2, 77-86.

Fig.7 further illustrates operation of the splitting unit. Fig.7a shows the example of an input image, Fig.7(b-f) show the images formed on outputs of the inverse Fourier processors 14_0 - 14_4, respectively, as a result of processing of the image shown in Fig.7a. The image of a low frequency channel 7b is carried from the output of the Fourier processor 14_0, being the output 7 of the splitting unit 2, to the input 9 of the assembly unit. The images of four high frequency channels are carried from the outputs of the Fourier processors 14_1 – 14_4, being another outputs of the splitting unit 2, to the corresponding inputs of the correlation unit 3 and to the inputs 10_1 – 10_4 of the assembly unit 5.

The further processing of these images will be described on example of one high frequency channel as said processing is identical in all high frequency channels.

Referring to Fig.3, the memory unit 15 stores the partial image of the processing channel. To compute the unnormalized correlation value, the center pixel value 21 and values of its neighboring pixels 22 are sequentially selected from the memory 15. Said values of neighboring pixels pass to the input of weighting summator 17, said summator implements the following operation on pixel values:

$$\mathbf{r} = \sum_{\mathbf{i}=1}^{\mathbf{N}} \mathbf{V_i} \bullet \mathbf{X_i}$$

where N is a number of pixels in neighborhood 22 of the central pixel (preferably N=8), V_i are the pre-defined weighting coefficients (preferably V_i=1/8) and X_i are the pixel values from neighborhood 22. The multiplicator 18 forms a product of the weighted sum of neighboring pixels and the central pixel value. This product is the unnormalized correlation value for the processing pixel. It is compared to the threshold value by dividing by said threshold value (output of the noise level measuring means 20) in divider 19. The result of said division is compared to 1.0 in the weighting unit 4. The processing described herein is repeated for all pixels of the partial image of the processing frequency channel.

The image of this frequency channel passes also to the noise level measuring means 20. The noise level from the output of means 20 is used as a threshold value to normalize correlation values by divider 19. As a result, the matrix containing the correlation values for all pixels of the processing frequency channel is formed on output of the correlation unit 3, said correlation values being normalized by the threshold value for the processing frequency channel.

The correlation values formed by the correlation unit 3 are carried to the weighting unit 4. Referencing to Fig.4, said correlation values for four frequency channels pass to inputs of the rounding means 231 - 23_4. Said rounding means decrease the data precision to 4 or 5 bits.

The four rounded values from outputs of means 23_1 – 23_4, each containing 4 or 5 bits, are assembled into one 16 or 20 bit word by the address assembling unit 24. The formed address is used as an input value for four look up tables 25_1 - 25_4. Each of said look up tables is a memory unit that stores values of the weighting coefficients for any combination of four correlation values in four

frequency channels, thereat such combination defines the address formed by the unit 24 in a unique way.

Fig.8 shows the preferred dependence of the weighting coefficient W_i in any of the frequency channels on the correlation value C_i in this channel and correlation values in other three channels, where Δ stands for the threshold value for this frequency channel. The weight W_i depends on the correlation value C_i and maximal correlation value L in other three frequency channels. This dependence is illustrated at Fig.8 by the curves:

curve A for $C_i \geq 0.7$ L,
curve B for $C_i = 0.5$ L,
curve C for $C_i = 0.3$ L,
curve D for $C_i = 0.1$ L and
curve E for $C_i = 0.01$ L.

The memory units 26_1 - 26_4 accumulate values of the weighting coefficients generated by look up tables 25_1 - 25_4. The address generator 27 and summators 28_1 - 28_4 smooth said weighting coefficients in each frequency channel. Said smoothing is obtained by summing in the summator (for example, 28_1) the center value of the coefficient and its neighboring values being sequentially selected from the memory unit (for example, 26_1) by the address generator 27. The smoothed values of weighting coefficients formed on outputs of summators (for example, 28_1) pass to the outputs of the weighting unit 4.

The operation of the assembling unit is described with a reference to Fig.5. The values of weighting coefficients for four frequency channels pass from the outputs of the unit 4 to the inputs 8_1 - 8_4 of multiplicators 29_1 - 29_4 and the pixel

values of the corresponding frequency channels are carried from outputs of the splitting unit 2 to another inputs 10_1 - 10_4 of said multiplicators. The products of said pixel values by the corresponding weighting coefficients generated by multiplicators pass to the inputs of the summator 30. Thereto the corresponding pixel value of the low frequency channel passes to the input 9 of said summator. Thereby the summator 30 calculates the value of the target pixel of the output image, said pixels are accumulated in the memory unit 6.

The embodiment described herein illustrates the method as applied to 2D scalar images. It is understood however that the claimed method may be applied similarly to 3D images. In this case, in the apparatus used to implement the claimed method: the number of frequency channel increases, the 3D Fourier processors are used instead of 2D ones and the number of neighboring pixels (used, for example, to compute a correlation value) is 26 instead of 8.

The claimed method may be applied also to processing of vector images, particularly the color images. Thereat, the 3 components of a vector presenting a pixel value may correspond for example to the intensity of the 3 basic colors for this pixel. In this case, the scalar operations on pixel values, like Fourier transform and summing, are replaced by the corresponding vector operations as it is known in the art and the correlation is computed as a scalar product of the center pixel value and the weighted vector sum of its neighbors, thereat the vector summator contains as many scalar summators as the number of vector components.

INDUSTRIAL APPLICABILITY

The image processing method according to the invention has the following advantages.

First, use of the correlation between the processing pixel and its neighboring pixels helps detect weak edges against a noisy background. This feature provides high noise suppression in conjunction with the emphasis of weak edges, thus significantly improving the image quality.

Furthermore, use of correlation between the processing pixel and its neighbors makes the method applicable to a wide variety of image types, including color images, gray scale images and 3D images.

Second, the determination of the threshold value by analysis of distribution of pixel values provides a high quality processing of images with the material difference in their noise levels without changing of parameters.

Third, the distortion-free reproduction of the large-scale image structures is achieved due to the separation of the low frequency channel.

CLAIMES

1. The image processing method, comprising the presentation of the original image as a matrix of the discreet picture elements (pixels), splitting of the original image into n frequency channels, each channel presented by an image matrix of the same size as the original image, the detection of edges, and assembling of the output image from said n frequency channels taking the detected edges into account, CHARACTERIZED BY splitting of the original image into the low frequency channel and n-1 high frequency channels and detection of edges by computation in each of n-1 selected high frequency channels for each pixel of the correlation between processing pixel and its neighboring pixels followed by comparison of said correlation value with correlation values for the corresponding (by their location in the image) pixels in other high frequency channels and with the threshold value for this channel; basing on the results of said comparison, the weighting coefficients are formed for each pixel of each of n-1 high frequency channels, and the assembly of the output image is made by summing each pixel from the low frequency channel with all the corresponding (by their location in the image) pixels of n-1 high frequency channels multiplied by their weighting coefficients.

2. The method according to claim 1, CHARACTERIZED BY determination of said weighting coefficient for each pixel of each of n-1 high frequency channels by comparison of the corresponding correlation value to the threshold value.

3. The method according to claim 2, CHARACTERIZED BY the specific dependence of the weighting coefficient on the correlation and threshold values:

- the weighting coefficient takes a minimal value for correlation values that are significantly smaller than the threshold value;
- the weighting coefficient smoothly increases from its minimal value to its maximal value for correlation values that are close to the threshold value;
- the weighting coefficient takes its maximal value for correlation values that are significantly larger than the threshold value.

4. The method according to claim 2, CHARACTERIZED BY the specific dependence of the weighting coefficient on the correlation and threshold values:

- the weighting coefficient takes a minimal value for correlation values that are significantly smaller than the threshold value;
- the weighting coefficient smoothly increases from its minimal value to its maximal value while the correlation value increases to the second threshold value, said second threshold value is equal to the product of the first threshold value by a pre-defined coefficient;
- the weighting coefficient smoothly decreases from its maximal value to its limit value while correlation value is larger than the second threshold value.

5. The method according to claim 1, CHARACTERIZED BY m of said n-1 high frequency channels, where 2<=m<=n-1, being different one from another in the direction of their principal passing only.

6. The method according to claim 5, CHARACTERIZED BY determination of said weighting coefficient for each pixel of each of m high frequency channels by comparison of the corresponding correlation value to the threshold value and to

the correlation values for corresponding (by their location in the image) pixels of other m-1 high frequency channels.

7. The method according to claim 1, CHARACTERIZED BY the picture element (pixel) being represented by a scalar value characterizing, for example, the image intensity at the corresponding pixel.

8. The method according to claim 7, CHARACTERIZED BY computation of said correlation value for each pixel by multiplication of said pixel value by the weighted sum of its neighboring pixels.

9. The method according to claims 8 and 5, CHARACTERIZED BY use of anisotropic weights for computation of said weighted sum of the neighboring pixels, thereat the direction of said anisotropy corresponds to the direction of principal passing for the processing frequency channel.

10. The method according to claim 7, CHARACTERIZED BY determination of said threshold value for each of said n-1 high frequency channels by analysis of distribution of pixel values in an image of the processing frequency channel.

11. The method according to claim 7, CHARACTERIZED BY determination of said threshold value for all said frequency channels by analysis of distribution of pixel values of the original image.

12. The method according to claim 1, CHARACTERIZED BY the picture element (pixel) being represented by a vector, components of said vector characterizing, for example, the intensity of the basic colors (red, green and blue) at the corresponding pixel.

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Replacement sheet

13. The method according to claim 12, CHARACTERIZED BY computation of said correlation value for each pixel as a scalar product of said pixel vector by the weighted sum of vectors representing its neighboring pixels.

14. The method according to claims 13 and 5, CHARACTERIZED BY use of anisotropic weights for computation of said weighted sum of the neighboring pixels, thereat the direction of said anisotropy corresponds to the direction of principal passing for the processing frequency channel.

15. The method according to claim 12, CHARACTERIZED BY determination of said threshold value for each of said n-1 high frequency channels by analysis of distribution of absolute values of vectors representing pixels of an image of the processing frequency channel.

16. The method according to claim 12, CHARACTERIZED BY determination of said threshold values for all high frequency channels by analysis of distribution of absolute values of vectors representing pixel values of the original image.

17. The method according to claim 1, CHARACTERIZED BY smoothing of the correlation values for several neighboring pixels before computation of the weighting coefficients, said smoothing being implemented at least in one of n-1 high frequency channels.

18. The method according to claim 17, CHARACTERIZED BY non linear transformation of the correlation values prior to the smoothing of the correlation values, said non linear transformation remains unchanged the values that are smaller or close to the threshold value, and decreases correlation values that are significantly larger than the threshold value.

19. The method according to claim 1, CHARACTERIZED BY smoothing of the weighting coefficients over several neighboring pixels, said smoothing being implemented at least in one of n-1 high frequency channels.

20. The method according to claim 1 CHARACTERIZED BY the input image being p dimensional matrix of picture elements, where p is greater or equal to 3.

21. The method according to claim 1, CHARACTERIZED BY use of different threshold values for different parts of the image, said different threshold values being used to form the weighting coefficients at least in one of n-1 high frequency channels.

22. The method according to claims 7 and 21, CHARACTERIZED BY determination of said threshold values for different parts of the image and different high frequency channels by the analysis of distribution of pixel values in the corresponding part of the image of the corresponding frequency channel.

23. The method according to claims 12 and 21, CHARACTERIZED BY determination of said threshold values for different parts of the image and different frequency channels by the analysis of distribution of absolute values of vectors representing pixels in the corresponding part of the image of the corresponding frequency channel.

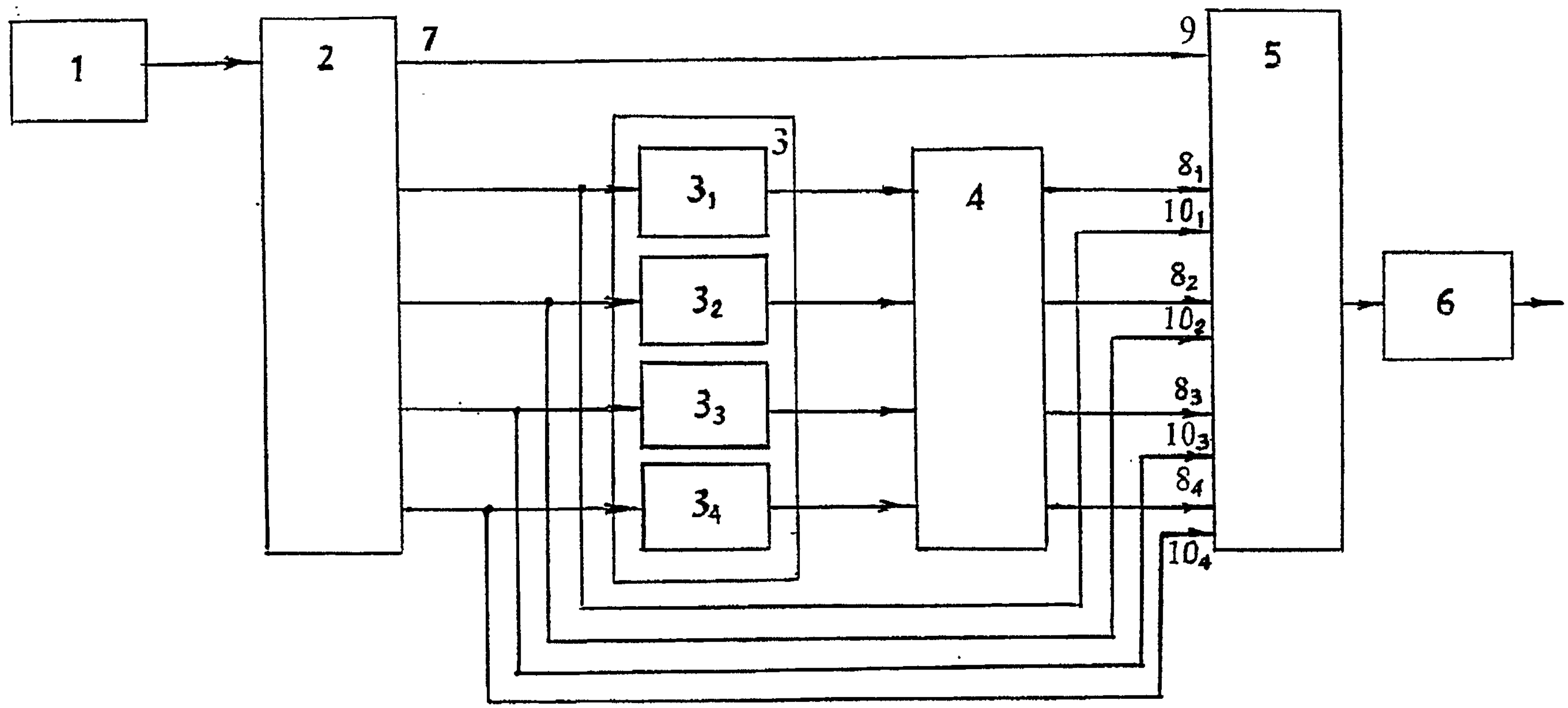

Fig.1

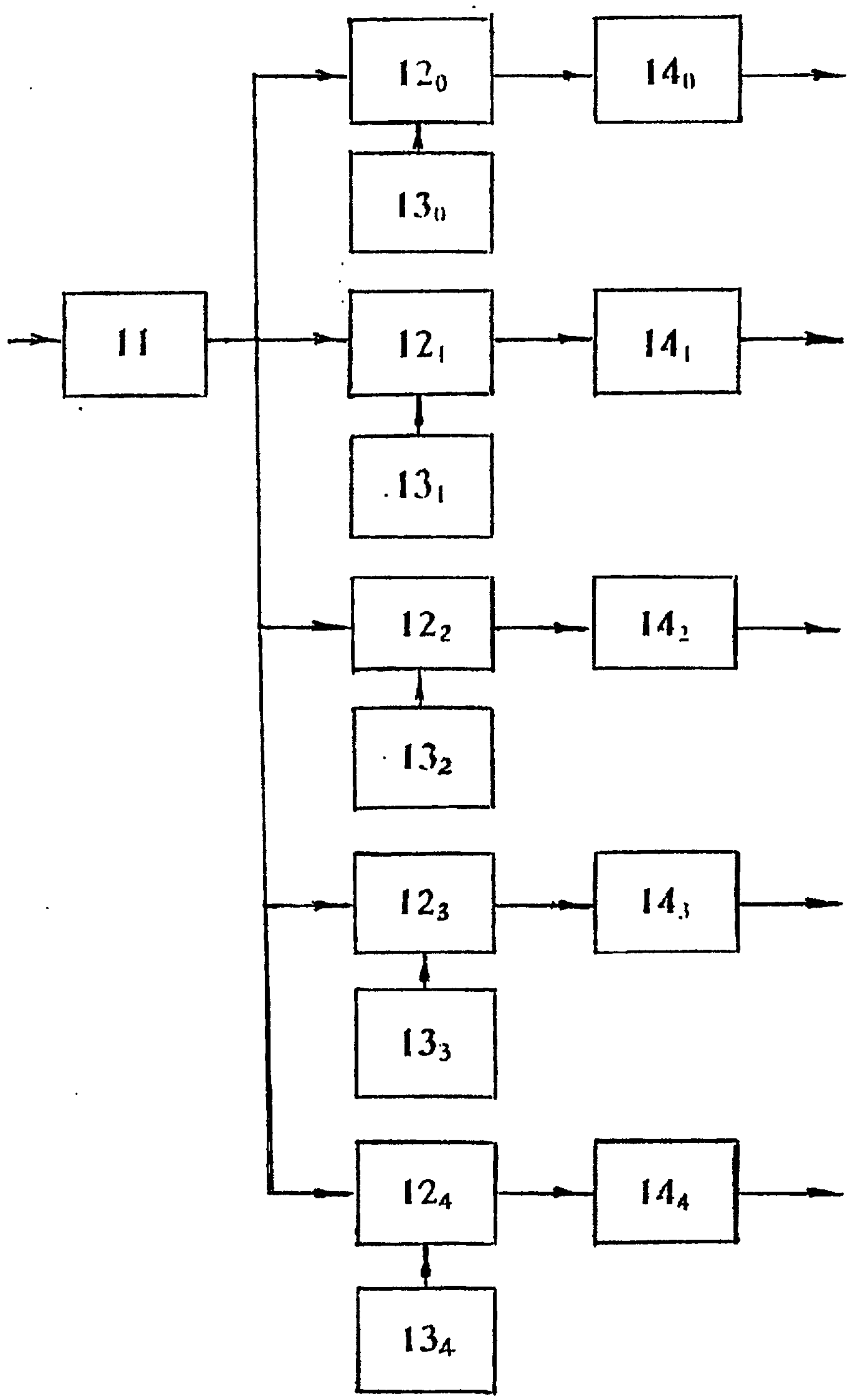

Fig.2

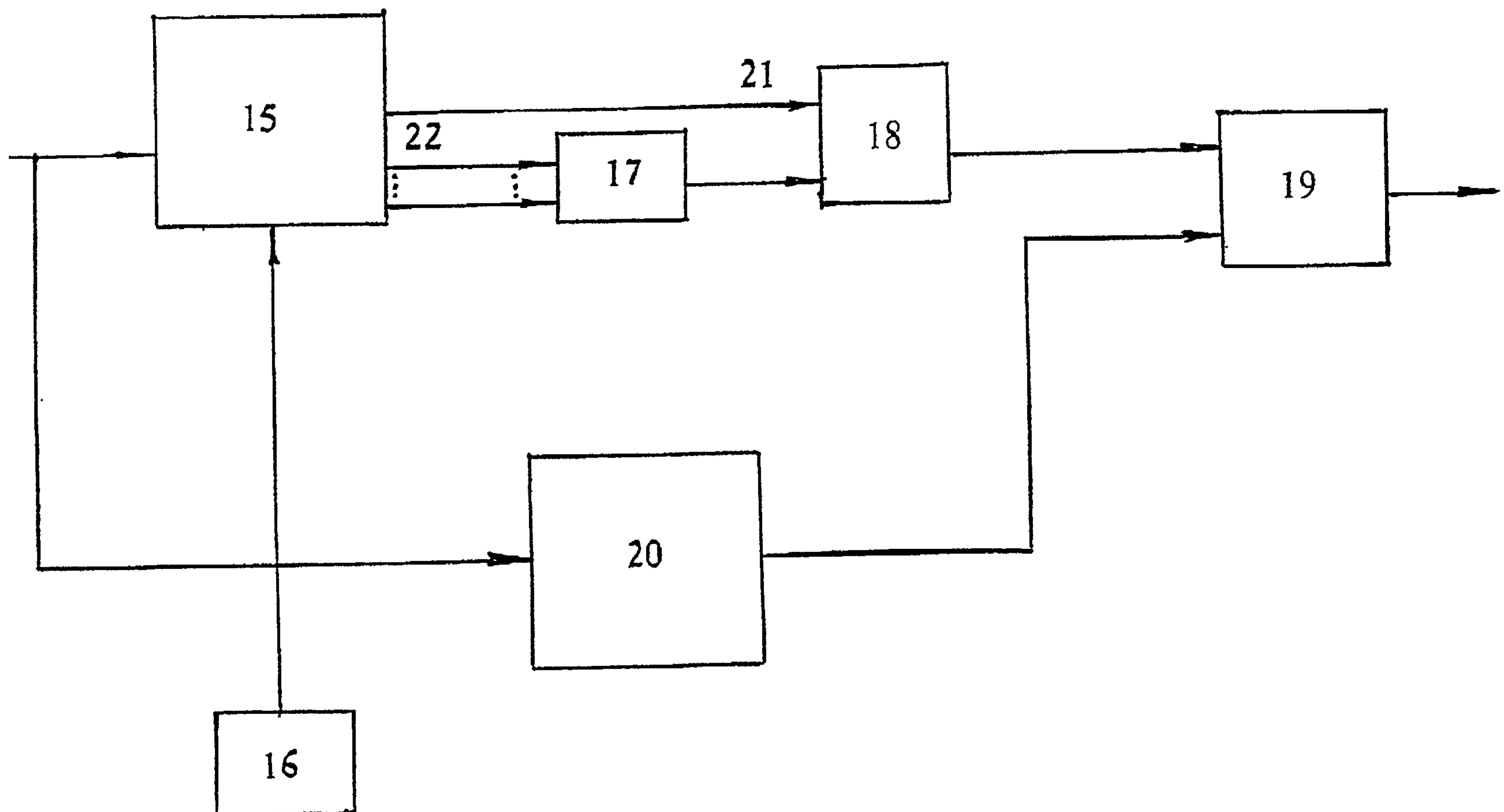

Fig.3

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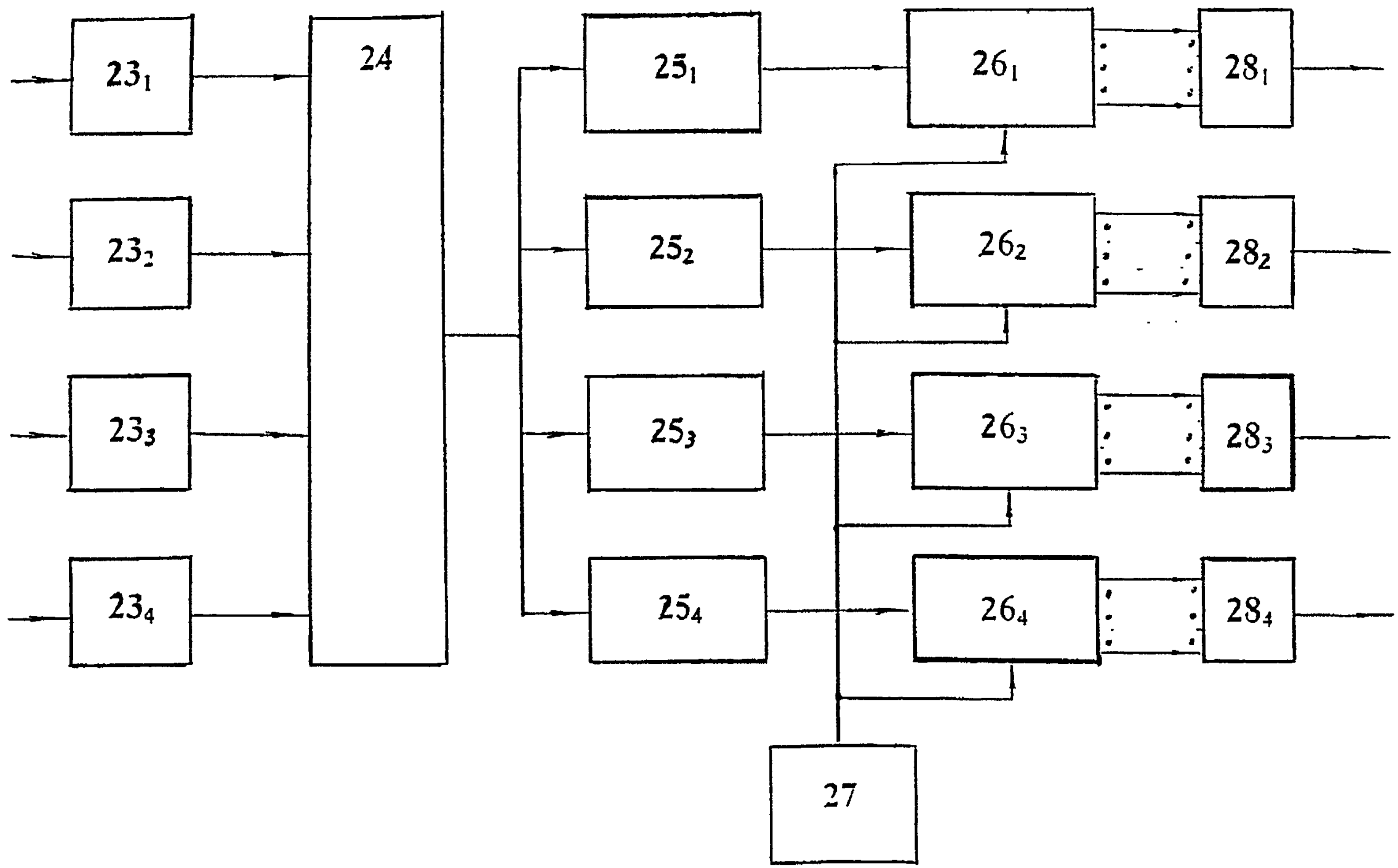

Fig.4

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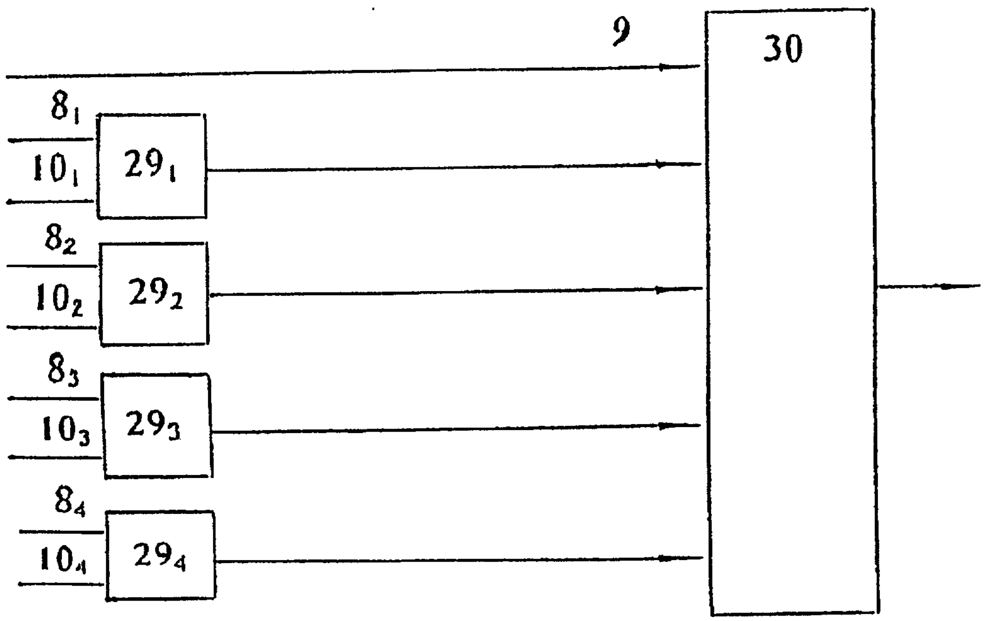

Fig.5

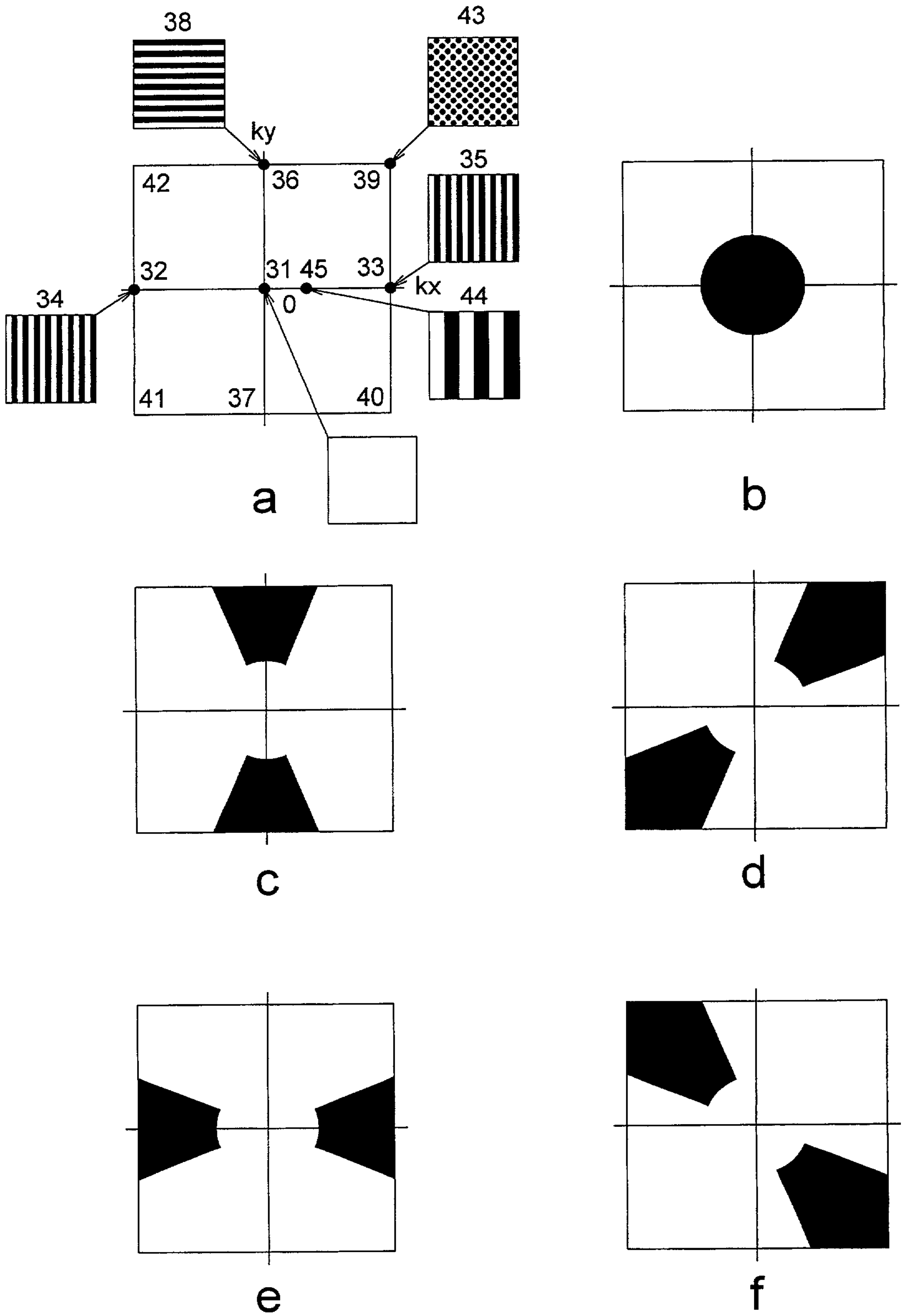

Fig.6

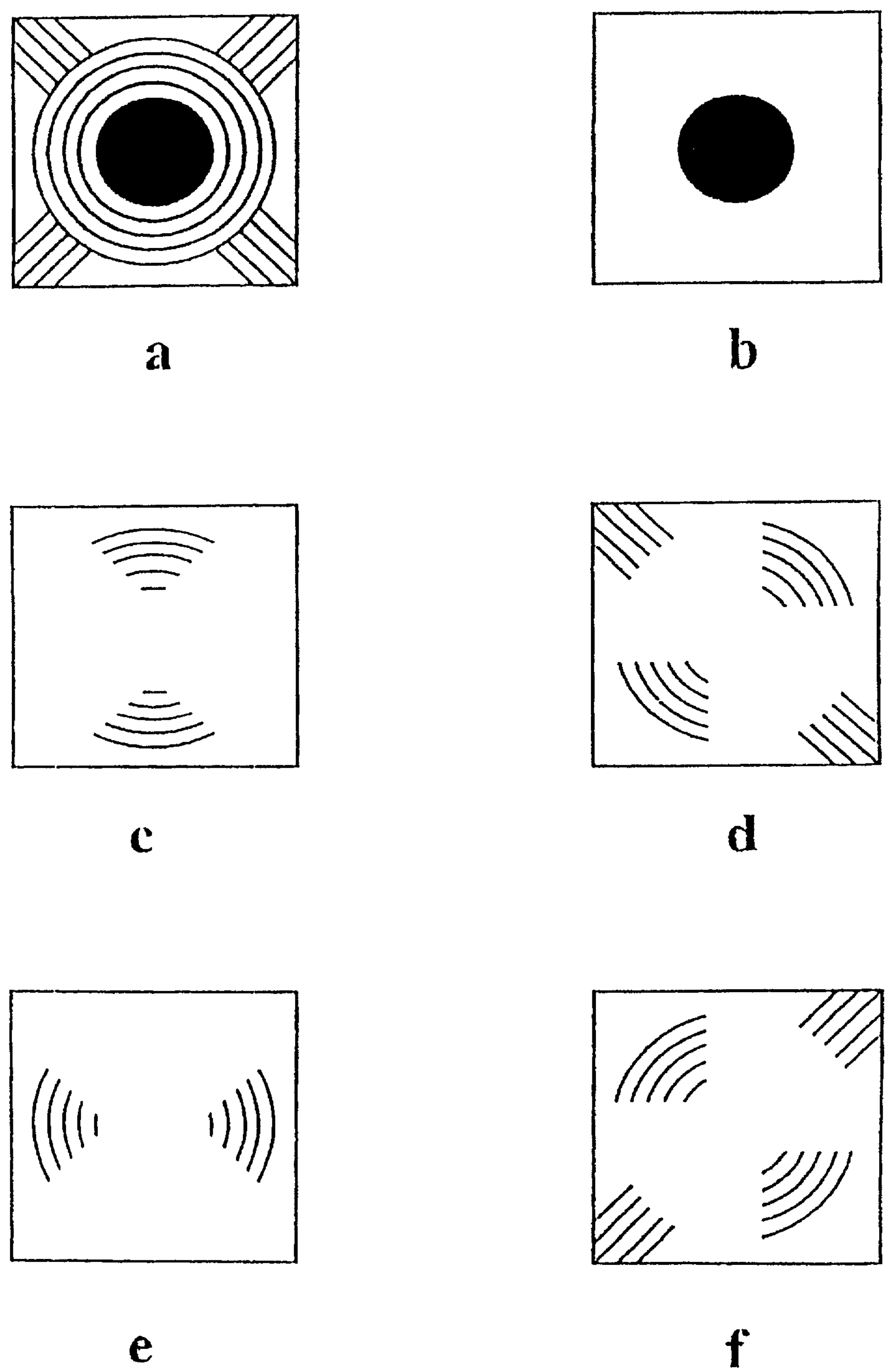

Fig.7

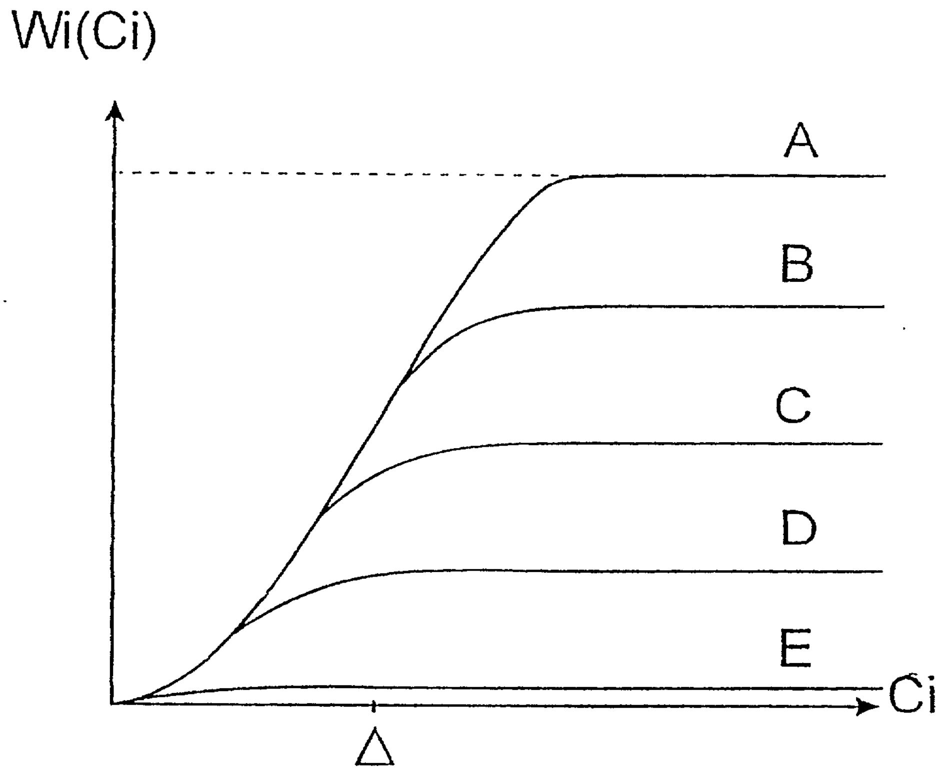

Fig.8

Combined Declaration and Power of Attorney
For U.S. Patent Application for
IMAGE PROCESSING METHOD

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

100 Full name of sole inventor: Michail Grigorievich SEMENCHENKO

Inventor's signature: M. Semenchenko Date: November 29, 2000

Residence: ul. Orbeli, 25-5-35, St. Petersburg, 194223, Russian Federation RUX

Post Office Address: same

Citizenship: Russian Federation

R0098263

COMBINED DECLARATION AND POWER OF ATTORNEY
(Original Application - Sole Inventor Priority Claimed)

As the below named inventor, I hereby declare

that my residence, post office address and citizenship are as stated near my name below;

that I believe I am the original, first and sole inventor of the subject matter of which is claimed and for which a patent is sought on the invention entitled

IMAGE PROCESSING METHOD,

which is described and claimed in the attached specification and amended by an amendment thereto submitted therewith (if any);

that I have reviewed and understand the contents of this specification, including the claims, as amended by any amendment referred to above;

that I do not know and do not believe the same was ever known or used in the United States of America before my invention thereof or patented or described in any printed publication, in any country before my invention thereof for more than one year prior to this application, or in public use or on sale in the United States of America more than one year prior to this application;

that the invention has not been patented or made the subject of an inventor's certificate issued before the date of this application in any country foreign to the United States of America on an application filed by me or my legal representatives or assigns more than twelve (12) months prior to this application;

that I acknowledge my duty to disclose information of which I am aware which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, Section 1.56(a); and

that no application for patent or inventor's certificate on this invention has been filed in any country foreign to the United States of America prior to this application by me or my legal representatives or assignees,

except as follows: PCT Application PCT/RU99/00272 (WO 00/14684) filed on 4 August 1999 and based on Russian application No. 98116546 filed on 3 September 1998.

I hereby appoint the following practitioner to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

Alexander D. Rabinovich Registration No. 37,425

I hereby appoint the practitioners associated with the Customer Number provided below to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith. Please address all correspondence and telephone calls to:

RADER, FISHMAN & GRAUER PLLC
39533 Woodward Avenue, Suite 140
Bloomfield Hills, Michigan 48304, U.S.A.
Phone (248) 594-0600; Fax (248) 594-0610

Customer Number: 010291

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